SEWAGE SLUDGE TREATMENT BY MEMBRANE ANEROBIC SYSTEM (MAS)

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ABSTRACT

The application of Membrane Anaerobic System (MAS) process treating the raw sewage sludge and the overall MAS treatment efficiency were investigated. The MAS consists of a cross-flow Ultra-filtration membrane for solid-liquid separation with operational pressure of 1.5 to 2 bars. An enrichment mixed culture of methanogenic bacteria was developed and acclimatized in the digester for three days when the seed sludge is fed into the 30 L digester. The raw sewage sludge was collected from Indah Water Municipal Treatment Plant at Taman Seri Mahkota-Kuantan. The digester was mixed semi-continuously for 4 days at two different concentrations of samples. Two concentration ratios of 50% and 100% of the raw sewage were studied. Results showed throughout the study, the removal efficiency of COD was 88.27% to 94.56%. The Nitrate-N removal was 99.44% to 99.77%. While the removal efficiency of Ammonia-N found 31.69% to 44.44%. About 99.99% of turbidity removal was achieved while the total suspended solids removal found 98.72% to 100%. The methane production rate was between 0.234 L/g COD/d to 0.325 L/g COD/d. The membrane anaerobic system, MAS treatment efficiency was greatly affected by solid retention time, hydraulic retention time and organic loading rates. In this study, membrane fouling and polarization at the membrane surface played a significant role in the formation of the strongly attached cake layer limiting membrane permeability.

ABSTRAK

Aplikasi sistem anaerobik membran (MAS) dalam rawatan kumbahan mentah telah dikaji. Dalam kajian ini, MAS terdiri daripada membran penapisan ultra yang mempunyai tekanan sebanyak 1.5-2.0 bar. Campuran kultur bakteria yang diperkaya dengan bakteria metanogen telah dihasilkan dan ditinggalkan selama 3 hari dalam 30 L reaktor supaya bakteria yang telah dikultur dapat membiasakan diri dalam persekitaran reaktor yang baru. Sampel kumbahan mentah telah diperoleh daripada tapak perawatan kumbahan Indah Water yang berada di Taman Seri Mahkota, Kuantan. Reaktor rawatan telah dicampurkan secara semi-campuran selama 4 hari masa penahan hidraulik (HRT). Sampel kumbahan yang mempunyai dua jenis kepekatan yang berlainan telah dikaji, iaitu kepekatan sebanyak 50% dan 100%. Keputusan kajian menunjukkan bahawa, rawatan bagi kadar permintaan oksigen kimia (COD) telah dikurangkan daripada 88.27% kepada 94.56%. Kekurangan unsur Nitrat-N adalah daripada 99.44% kepada 99.77%. Manakala, kekurangan unsur Ammonia-N didapati daripada 31.69% kepada 44.44%. Sebanyak 99.99% daripada kekeruhan cecair dapat dikurangkan manakala keseluruhan tahanan pepejal (TSS) telah dikurangkan daripada 98.72% kepada 100%. Kadar penghasilan gas metana adalah diantara 0.234L/g COD/d dan 0.325L/g COD/d. Tahap kecekapan perawatan kumbahan dengan mengunakan sistem anaerobik membran dipengaruhi oleh masa penahanan pepejal (SRT), masa penahanan hidraulik dan kadar muatan organik. Dalam kajian ini, kerosakan membran dan pembibiran pada permukaan membran memainkan peranan penting dalam penghasilan lapisan kek yang tebal justeru mengurangkan keberkesanan lapisan resapan membran.

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LIST OF SYMBOLS/ABBREVIATION

3MAS	Membrane Anaerobic System
COD	Chemical Oxygen Demand (mg/L)
CH_4	Methane
HRT	Hydraulic Retention Time (day)
BOD	Biological Oxygen Demand
CO_2	Carbon Dioxide
H_2O	Water
$K_2Cr_2O_7$	Potassium Dichromate
μ_{max}	Maximum Growth Rate
RO	Reverse Osmosis
LR	Lower Range
HR	Higher Range
NaOH	Sodium Hydroxide
CUF	Crossflow Ultrafiltration
TSS	Total Suspended Solid (mg/L)
MWCO	Molecular Weight Cut-Off
PVC	Polyvinylchloride
MF	Microfiltration
cBOD	Carbonaceous Biological Oxygen Demand
CUMAR	Crossflow Ultrafiltrafiltration Membrane Anaerobic Reactor

CHAPTER 1

INTRODUCTION

1.1 Background of Research

Anaerobic digestion is a biological process that happens in environment. It occurs naturally in swamps, water-logged soils and paddy fields, deep bodies of water, estuaries and in the digestive systems of termites and large animals. It utilizes microorganisms to break down biodegradable organic materials with little or in the absence of oxygen. Almost any organic material can be processed with anaerobic digestion including waste papers, agriculture wastes, industrial effluents, leftover food, animal and human excreta. It is widely used for the treatment of wastewater sludge in many industries.

Due to the high organic fraction, anaerobic digestion is one of the fundamental processes in sewage sludge treatment for reducing and stabilizing the organic solids. There are more innovative waste treatment facilities attributed to improve anaerobic digestion technology. With the advancement of membrane technology, application of membrane filtration in the treatment of sewage sludge can contribute to developing an efficient sewage sludge treatment process that is capable of retaining biomass concentration within the reactor and producing high quality effluent. Membrane separation techniques have proven to be an effective method in separating biomass solids from digester. (Liew, *et al.,* 2005).

Sludge digestion occurs in anaerobic digesters. It produces conditions that encourage the natural breakdown of organic matter by bacteria in the absence of air.

Utilizing anaerobic digestion technologies can help to reduce the emission of greenhouse gasses in a number of key ways:

- Replacement of fossil fuels
- Reducing methane emission from landfills
- Displacing industrially-produced chemical fertilizers
- Reducing vehicle movements
- Reducing electrical grid transportation losses

Anaerobic digestion is a renewable energy source because the process produces biomethane which consist of methane (50%-80%), a powerful greenhouse gas helping replace fossil fuels. Methane is a gas that contains molecules of methane with one atom of carbon and four atoms of hydrogen (CH_4). It is the major component of the "natural" gas used in many homes for cooking and power generation. As methane is about twenty times more potent as carbon dioxide this has significant negative environmental effects. Besides, anaerobic digestion also releases carbon dioxide (20%-50%) and traces levels of other gases such as hydrogen, carbon monoxide, nitrogen, oxygen and hydrogen sulfide. The relative percentage of these gases depends on the feed material and management of the process.

Methane and power produced in anaerobic digestion facilities can be utilized to replace energy derived from fossil fuels, and hence reduce emissions of greenhouse gasses. Increasingly however, anaerobic digestion is seen not as a process for stabilizing sludge, but as an opportunity to recover the energy embedded in the substrate, traditionally in the form of methane. For instance it has been estimated that conventional anaerobic digestion of the UK's municipal solid waste could generate 1.4GW electricity or 1.9% of the nations demand (Abdurahman; 2000).

1.2 Problem Statement

In today's urbanized society, domestic sewage which consists of human and animal wastes, household wastes, small amounts of groundwater infiltration and small amounts of industrial wastes is discharged to streams, rivers, lakes and oceans. This can lead to severe water pollution when an overwhelming amount of waste accommodates in natural ecosystem. Hence it is very important to prevent the pollution of vital and limited resources of water by providing adequate treatment of liquid waste emanating from domestic sources.

The most significant components of sewage are usually suspended solids, biodegradable organics, and pathogens. Higher accumulations of these components can lead to high levels of organic pollution. Consequently, when the wastes are not destroyed as fast as they are produced, they make it unfavorable to humans and many other organisms. The anaerobic digestion of sewage sludge is considered as an excellent alternative to dumping, composting, incinerating of organic waste or to simple fermentation processes (Abdurahman, 2000).

The anaerobic process is time-tested does not require the purchase of special bacteria or nutrients. This is because the bacteria are anaerobic and they do not require oxygen like the organisms in an aerobic process. By using anaerobic digestion in the treatment of wastewater sludge, the overall cost of sewage treatment is reduced and it also furnishes a considerable power supply. Although many sludge stabilization methods exist, anaerobic digestion is unique for it has the ability to produce a net energy gain in the form of methane gas; it optimizes cost effectiveness and minimizes the amount of final sludge disposal, thus decreasing the hazards of wastewater and sewage treatment by-products. Thus for municipal wastewater treatment plants it is most cost effective and environmentally sound to use anaerobic digestion in the stabilization of sewage sludge. Besides, this process is helping clients to convert liabilities into assets and green energy; that is "From Waste to Energy".

1.3 Research Objectives

In the course of completing this research, there are few objectives to be fulfilled. Those are:

i. To evaluate the overall MAS treatment efficiency.

ii. To evaluate the influence of the hydraulic retention time and sewage concentration on turbidity, Chemical Oxygen Demand (COD), Ammonia-Nitrogen, Nitrate-Nitrogen, Total Suspended Solid (TSS) and methane yield.

1.4 Scope of Research

To accomplish the objectives of this research, the scope of this research focuses in:

- A 30 L digester is designed and used to treat sewage sludge which was taken from Indah Water Treatment Plant.

- Hollow fiber ultrafiltration membrane was used to increase the efficiency of the treatment with the following operational conditions:
  - The temperature of the process is in the mesophilic range, between 25°C-45°C.
  - The pressure to be used is 1.5-2.0 bars.
  - The pH of the reactor content is in the range of 6.5 to 7.5.
  - The laboratory digester is completely mixed semi-continuously.

- An enrichment mix culture of methanogenic bacteria was acclimatized in the digester after sample feeding.

- The next scope was to examine the influence of hydraulic retention time and different sewage concentration on turbidity, Chemical Oxygen Demand (COD), ammonia-nitrogen, nitrate-nitrogen and Total Suspended Solid (TSS).

- Finally this study measured methane gas production by using 20 L water displacement bottle and J-Tube technique.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

Anaerobic fermentation is one of the oldest processes used in stabilization of solids and biosolids. It involves the decomposition of organic matter and inorganic matter such as ammonia and nitrate to digested particles in the absence of oxygen.

The major application of anaerobic digestion is applied in the stabilization of sewage sludge. Later on, it was successfully used for the treatment of industrial and domestic wastewaters. Mass reduction, methane production, and improved dewatering properties of the fermented sludge are important features of anaerobic digestion.

Anaerobic digestion consist of a series of microbiological processes that convert organic compounds to methane and carbon dioxide, and reduce volatile solids by 35 percent to 60 percent, depending on the operating conditions (U.S. EPA, 1992a; Gabriel, 2005). A net reduction in the quantity of solids and destruction of pathogenic organisms are also accomplished in the anaerobic digestion. Furthermore, anaerobic digestion of municipal sewage sludge can produce sufficient amount of digester gas to meet most of the energy needs for the plants.

2.2 Advantages and Disadvantages of Anaerobic Digestion

Anaerobic digestion offers several advantages and disadvantages over aerobic digestion and the methods of sludge stabilization, which include:

- The methane gas produced is a source of usable energy. In most cases the energy produced exceeds the energy required to maintain the temperature for sludge digestion. Excess methane can be used for heating building, running engines for aeration blowers, or generating electricity.
- Reduction in total sludge mass through the conversion of organic matter primarily to methane, carbon dioxide and water. Commonly, 30% to 65% of the raw sludge solids are destroyed. This can significantly reduce the cost of sludge disposal.
- The digested solids are generally free of objectionable odors.
- The digested biosolids contain nutrients such as nitrogen and phosphorus, and organic matter that can improve the fertility and texture of soils.
- A high rate of pathogen distribution can be achieved, especially with the thermophilic digestion process.
- There is a reduction of energy required for wastewater treatment.
- Anaerobic digestion is suitable for high-strength industrial wastes.
- There is preservation of the activity of anaerobic microorganisms, even if the digester has not been fed for long periods of time.
- Anaerobic systems can biodegrade xenobiotic compounds such as chlorinated aliphatic hydrocarbons (e.g., trichloroethylene, trihalomethanes) and recalcitrant natural compounds such as lignin (Gabriel, 2005).

Some disadvantages of anaerobic sludge digestion are:

- It is a slower process.

- The capital cost is high because it requires large closed digestion tanks fitted with systems for feeding, heating, and mixing the sludge.

- Large reactors are required to provide the hydraulic retention time in excess of 10days to stabilize the sludge effectively (Gabriel, 2005). This slow digestion process also limits the speed with which the system can adjust to changes in waste loads, temperature, and other environment conditions.

- Microorganisms involved in anaerobic digestion are sensitive to small changes in the environment. Therefore, the process is susceptible to upsets. Monitoring the performance, and close process control are required to prevent upsets.

- The process produces poor-quality sidestream. Supernatants often have a high oxygen demand and a high concentration of suspended solids, nitrogen, and phosphorus. These flows may require additional treatment before recycling to the influent flows in plants that are required to remove nitrogen and phosphorus from wastewater (Gabriel, 2005).

2.3 Chemical Oxygen Demand

Chemical oxygen demand (COD) is the amount of oxygen necessary to oxidize the organic carbon completely to CO_2, H_2O, and ammonia (Gabriel, 2005). Chemical oxygen demand is measured via oxidation with potassium dichromate ($K_2Cr_2O_7$) in the presence of sulfuric acid and silver and is expressed in mg/L. Thus, COD is a measure of the oxygen equivalent of the organic matter as well as microorganisms in the wastewater (Gabriel, 2005). If the COD value is much higher than the BOD value, the sample contains large amounts of organic compounds that are not easily biodegrade.

2.4 Factors Controlling Anaerobic Digestion

Anaerobic digestion is affected by temperature, pH, retention time, chemical composition of wastewater, competition of methanogens with sulfate-reducing bacteria, and the presence of toxicants.

2.4.1 Temperature

Methane production has been documented under a wide range of temperatures ranging between 0°C and 97°C. Although pcychrophilic methanogens have not been isolated, thermophilic strains operating at an optimum range of 50°C-75°C occur in hot springs. *Methanothermus fervidus* has been found in a hot spring in Iceland and grows at 63-97°C (Sahm, 1984).

In municipal wastewater treatment plants, anaerobic digestion is carried out in the mesophilic range at temperature from 25°C to up to 40°C, with an optimum at approximately 35°C. Thermophilic digestion operates at temperatures ranges of 50°C -65°C. It allows higher loading rates and is also conducive to greater destruction of pathogens. One drawback is its higher sensitivity to toxicants (Koster, 1988).

Because of their slower growth as compared to acidogenic bacteria, methanogens are very sensitive to small changes in temperature. As to utilization of volatile acids by methanogens, a decrease in temperature leads to a decrease of the maximum growth rate (μ_{max}), while the half saturation constant K_s increases (Gabriel, 2005). Thus, mesophilic digester must be designed to operate at temperature of 30°C -35°C for their optimal functioning.

2.4.2 Retention Time

The hydraulic retention time (HRT), which is depends on wastewater characteristics and environmental conditions, must be long enough to allow metabolism by anaerobic microorganisms in digesters. Digesters based on attached growth have a lower HRT (1-10 days) than those based on dispersed growth (10-60 days). The retention times of mesophilic and thermophilic digesters range between 25 and 35 days, but can be lower. Hydraulic retention time (HRT), which is the average time the liquid sludge is held in the digester. It can be defined operationally as follows: (Turovskiy and Mathai, 2006).

- HRT, in days, is equal to the volume of sludge in the digester (m^3) divided by the volume of digested sludge withdrawn daily (m^3/d).

2.4.3 pH

Most methanogens function optimally at a pH range of 6.8-7.5, but optimally at pH 7.0-7.2, and the process may fail if the pH is close to 6.0. Acidogenic bacteria produce organic acids that tend to lower the pH of the bioreactor. Under normal conditions, this pH reduction is buffered by bicarbonate produced by methanogens. Under adverse environmental conditions, the buffering capacity of the system can be upset, eventually stopping methane production. Acidity is inhibitory to methanogens than to acidogenic bacteria. An increase in volatile acids level thus serves as an early indicator of system upset. Monitoring the ratio of total volatile acids (as acetic acids) to alkalinity (as calcium carbonate) has been suggested to ensure that it remains below 0.1 (Sahm, 1984). One method for restoring the pH balance is to increase alkalinity by adding chemicals such as lime, anhydrous ammonia, sodium hydroxide, or sodium bicarbonate.

2.4.4 Toxicants

A wide range of toxicants are responsible for the occasional failure of anaerobic digester. Toxicity becomes less severe, however, once the anaerobic microorganisms become adapted to the toxic wastewater (Lettinga, 1995). Inhibition of methanogenesis is generally indicated by reduced methane production and increased concentration of volatile acids.

2.4.5 Chemical Composition of Wastewater

Methanogens can produce methane from carbohydrate, proteins and lipids, as well as from complex aromatic compounds (e.g. ferulic, vanillic, and syringic acids). However, a few compounds such as lignin and n-paraffin are hardly degraded by anaerobic microorganisms.

Wastewater must be nutritionally balances (nitrogens, phosphorus, sulfur, etc.) to maintain an adequate anaerobic digestion. Phosphorus limitation results in reversible decrease in methanogenic activity. The C:N:P ratio for anaerobic bacteria is 700:5:1 (Lettinga, 1995; Sahm, 1984). However, some investigators argue that the C/N ratio for optimal gas production should be 25-30: 1(Turovskiy and Mathai, 2006). Methanogens use ammonia and sulfide as nitrogen and sulfur sources, respectively. Although un-ionized sulfide is toxic to methanogens at levels exceeding 150-2mg/L, it is required by methanogens as a major source of sulfur (Speece *et al.*, 1983). Moreover, trace elements such as iron, cobalt, molybdenum, and nickel are also necessary. Nickel, at concentration as low as 10µM, significantly increases methane production in laboratory digesters (Turovskiy and Mathai, 2006). Nickel addition can increase the acetate utilization rate of methanogens from two to as high as 10g acetate g^{-1} VSS day^{-1} (Speece *et al*., 1983). Nickel enters in the composition of the co-factor F_{430}, which is involved in biogas production (Turovskiy and Mathai, 2006).

2.4.6 Suspended Solids

Solids suspended in wastewater consist of inorganic or organic particles or of immiscible liquids. Domestic wastewater usually contains large quantities of suspended solids that are mostly organic in nature. Suspended material is aesthetically displeasing and provides adsorption sites for chemicals and biological agents. Organic solids may be degraded biologically, resulting in objectionable by-products. Biologically active suspended solids may include disease-causing organisms such as toxin-producing strains of algae.

2.5 Process Microbiology

A group of microorganism species, especially bacteria and methanogens, are involved in the transformation of high-molecular-weight organic compounds to methane. Moreover, synergistic interactions between the various groups of microorganisms are implicated in anaerobic digestion of wastes. The overall reaction is shown in Eq. 2.1 (Gabriel, 2005).

$$\text{Organic matter} \longrightarrow CH_4 + CO_2 + H_2 + NH_3 + H_2S \qquad \text{Eq. 2.1}$$

Large numbers of strict and facultative anaerobic bacteria such as *Bacteroides, Bifidobacterium, Clostridium, Lactobacillus* and *Streptococcus* are implicated in the hydrolysis and fermentative of organic compounds (Gabriel, 2005). Four categories of microorganisms are involved in the transformation of complex materials into simple molecules such as methane and carbon dioxide. These microbial groups operate in a synergistic relationship (Barnes and Fitzgerald, 1987; Koster, 1988; Sahm, 1984; Gabriel, 2005) as shown in Figure 2.1.

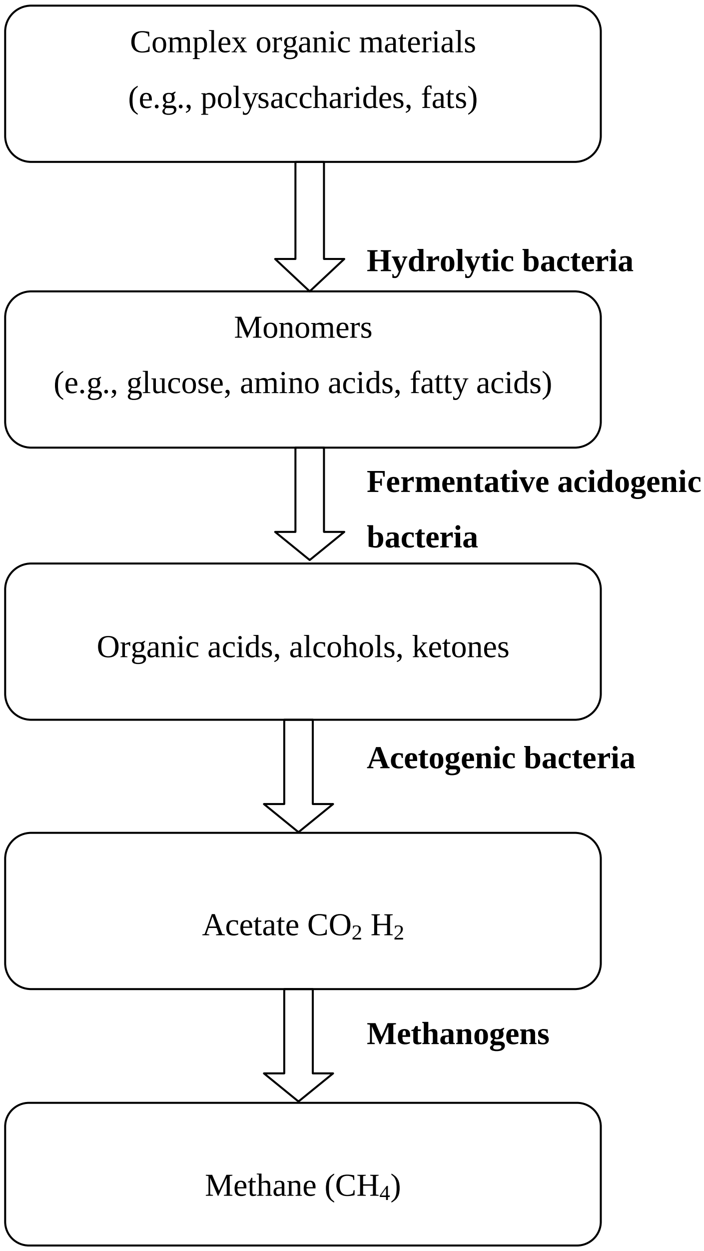

Figure 2.1: Metabolic bacterial groups involved in anaerobic digestion of wastes.

2.5.1 Hydrolytic Bacteria

Consortia of anaerobic bacteria break down complex organic molecules (e.g., proteins, cellulose, lignin, lipids) into soluble monomer molecules such as amino acids, glucose, fatty acids, and glycerol. The monomers are directly available to the next group of bacteria. Hydrolysis of complex molecules is catalyzed by extracellular enzymes such as cellulases, protease, and lipases. However, the hydrolytic phase is relatively slow and can be limiting in anaerobic digestion of wastes such as raw cellulytic wastes that contain lignin (Speece, 1983; Gabriel, 2005). Hydrolysis is the rate limiting step in the acid-forming phase (Eastman and Ferguson, 1981; Turovskiy and Mathai, 2006).

2.5.2 Fermentative Acidogenic Bacteria

Acidogenic that is acid forming bacteria such as *Clostridium* converts sugars, amino acids, and fatty acids to organic acids (e.g., acetic, propionic, formic, lactic, butyric, or succininc acids), alcohols and ketones (e.g., ethanol, methanol, glycerol, and acetone), acetate, CO_2 and H_2. Acetate is the main product of carbohydrate fermentation. The products formed vary with the bacterial type as well as with culture conditions such as temperature, pH and redox potential. (Gabriel, 2005).

2.5.3 Acetogenic Bacteria

Acetogenic bacteria- acetate and hydrogen producing bacteria such as *Syntrobacter wolinii* and *Syntrophomonas wolfei* (Gabriel, 2005) converts fatty acids (e.g., propionic acid, butyric acid) and alcohols into acetate, hydrogen and carbon dioxide, which are used by the methanogens. This group requires low hydrogen tensions for fatty acid conversion, necessitating a close monitoring of hydrogen concentration. Under relatively high hydrogen partial pressure, acetate formation is reduced and the substrate is converted to propionic acid, butyric acod, and ethanol rather than methane. There is a symbiotic relationship between acetogenic bacteria and methanogens. Methanogens help to achieve the low hydrogen tension required by acetogenic bacteria. (Gabriel, 2005)